

## Wall Relaxation

Mike Hayden  
Simon Fraser University

Background

Some existing data

Some thoughts on how to proceed

## Surface Adsorption

(Classical) non-interacting 2-D gas  
in thermal equilibrium with bulk

Equating chemical potentials

$$k_B T \ln\left(\frac{N_s \Delta^2}{S}\right) - E_B = k_B T \ln\left(\frac{N_v \Delta^3}{V}\right)$$

# atoms in adsorbed phase      surface area      binding energy (relative to bulk)      # atoms in bulk phase      volume  
 de Broglie wavelength

$$\Delta = \sqrt{\frac{2\pi\hbar^2}{m k_B T}}$$

leads to

$$\sigma = n \Delta \exp\left(\frac{E_B}{k_B T}\right)$$

surface density      volume density

or, for localized adsorption

$$\frac{\sigma}{\sigma_s \Delta^2} = n \Delta \exp\left(\frac{E_B}{k_B T}\right)$$

surface density of adsorption sites

also,

mean time btwn wall collisions  $t_v = \frac{4V}{\bar{v}S}$  with  $\bar{v} = \sqrt{\frac{8k_B T}{\pi m}}$

mean adsorption time  $t_a = \frac{4\Delta}{\bar{v}B} \exp\left(\frac{E_B}{k_B T}\right)$   
(Frenkel Law)      sticking probability

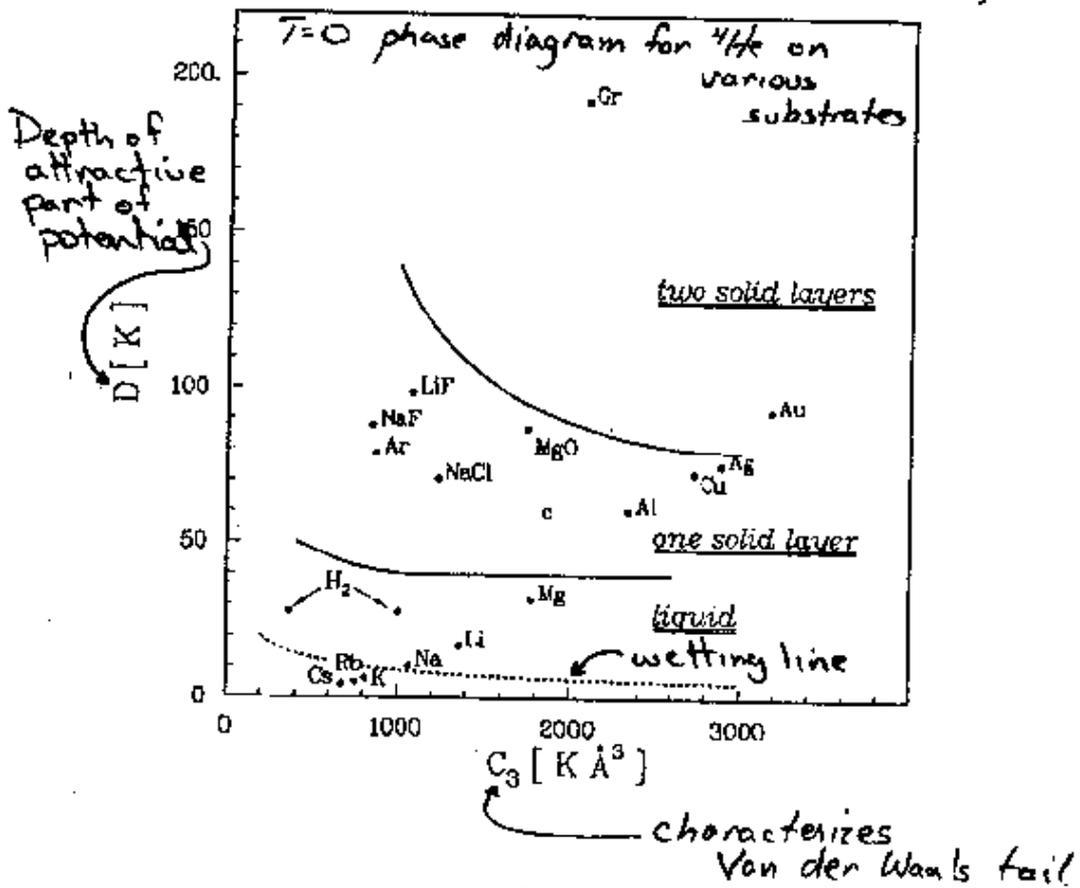
---

or, for localized adsorption  $t_a = \frac{4\Delta^3 \sigma_s}{\bar{v}B} \exp\left(\frac{E_B}{k_B T}\right)$

# Nature of the ${}^4\text{He}$ /substrate interface

3

J. Treiner, JLT9 92, 1 (1993)



$$V_{\text{sub}} = \frac{4}{27 D^2} \left( \frac{C_3}{Z^3} \right)^3 - \frac{C_3}{Z^3}$$

## Bound States for $^3\text{He}$ at or near interface?

E. Krotscheck / M. Saarela : no  $^3\text{He}$  surface bound states for substrates as weak as Na

[see Agnolet et al. JLTIP 10/ 445 (1995)

and Clements et al. Czech. J. Phys. 46 S1 285 (1996)]

Experimental data?

Indirect evidence that  $E_B$  is not large, but no systematic studies at the level of 1K or less.

Is a weak-binding coating required?

not a priori

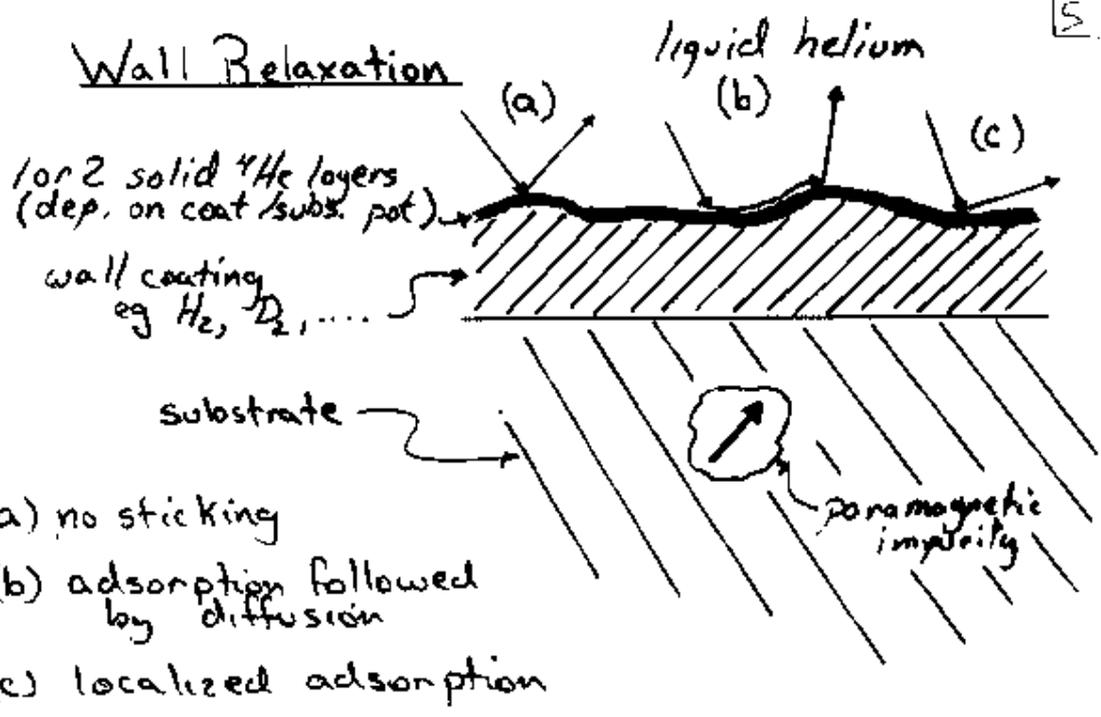
$\Rightarrow$  only if the substrate itself has paramagnetic impurities

see for eg. Lefebvre-Sequin + Brosse JLTIP 32/85  
1988

for long relaxation times, achieved on "bare glass" and even  $\text{O}_2$  on  $\text{O}_2/\text{He}$  substrates

Question: has anyone measured the magnetic susceptibility of d-TAB?

# Wall Relaxation



In each case, spectral density of field fluctuations  $\delta B$  experienced by  $^3\text{He}$  atom during encounter with wall is non-zero at Larmor frequency

If the correlation time  $\tau_c$  for these fluctuations is short enough that

$$\tau_c \gamma \langle \delta B^2 \rangle^{1/2} \ll 1$$

the wall relaxation rate is  $\frac{1}{T_{1a}} = \gamma \langle \delta B^2 \rangle \tau_c \frac{1}{1 + \omega_0^2 \tau_c^2}$   
 ( $\omega_0 = \gamma B_0$ )

or, if wall relaxation is the only NB effect in the cell

$$\frac{1}{T_1} = \frac{N_a}{N_V} \frac{1}{T_{1a}} = \frac{S \Delta}{V} \langle \delta B^2 \rangle \frac{\tau_c}{1 + \omega_0^2 \tau_c^2} \exp\left(\frac{E_0}{kT}\right)$$

Temperature dependence of relaxation rate?

A. "High temperature" ( $\frac{E_D}{10} < kT < E_B$  ?)

① Free diffusion on surface

<u>Correlation time</u>	<u>Relaxation rate</u>
• indep. of temp. -----	$\rightarrow \sim T^{-1/2} \exp(E_D/kT)$
• time of flight across cell $\tau_c = \frac{L_s}{v} \sim T^{-1/2}$ -----	$\rightarrow \sim T^{-1} \exp(E_D/kT)$
• adsorption time $\tau_c = \tau_a \sim T^{-1} \exp(\frac{E_D}{kT})$ -----	$\rightarrow \sim T^{-3/2} \exp(2E_D/kT)$

② Localized adsorption

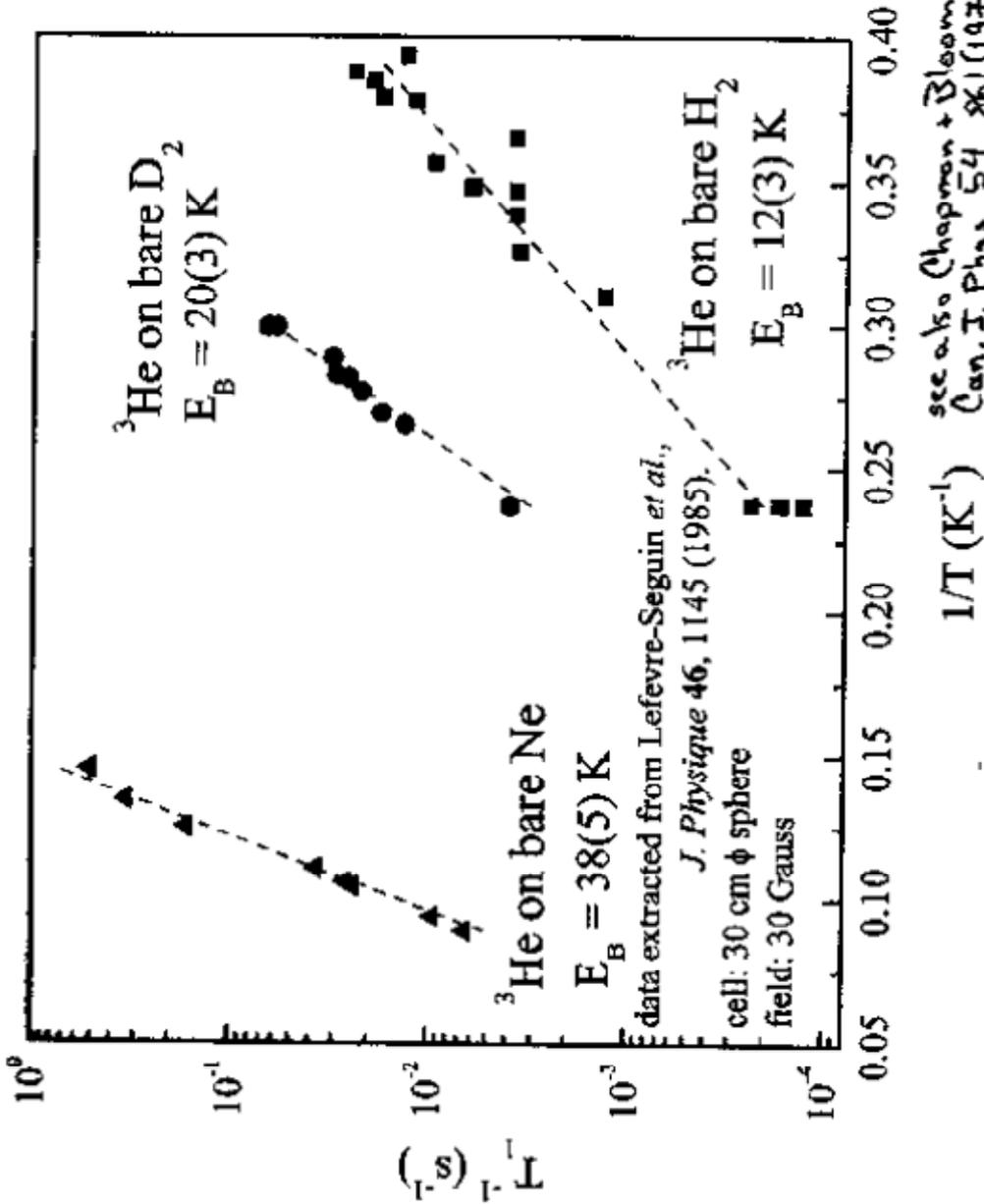
<u>Correlation time</u>	<u>Relaxation rate</u>
• indep. of temp. -----	$\rightarrow \sim T^{-3/2} \exp(E_D/kT)$
• partial mobility $\tau_c \sim \exp(\frac{E_D^*}{kT})$ -----	$\rightarrow \sim T^{-3/2} \exp(\frac{E_D + E_D^*}{kT})$
• adsorption time $\tau_c = \tau_a \sim T^{-2} \exp(\frac{E_D}{kT})$ -----	$\rightarrow \sim T^{-3/2} \exp(\frac{2E_D}{kT})$

### B. "Low temperature" ( $kT \approx E_0/10$ )

- Adsorption time  $t_a$  becomes so long that another mechanism likely limits the correlation time  $\tau_c$ .
- Density and interactions between adatoms become a concern.\*

General comment: hard to determine exact temp. dependence w/o scanning a large range in temperature  
(Thermometry is an issue!)

- \* Piegay and Tostevin *JLTP* 126, 157 (2002) note observation of a density dependent wall form above 1K BUT the effect is such that it is most likely associated with the s.f. film!



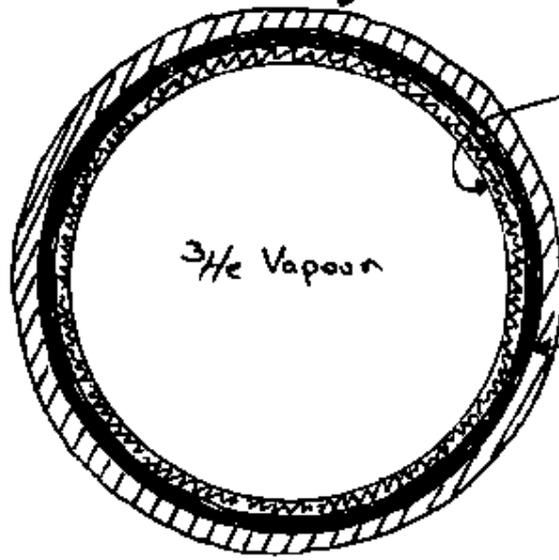
see also Chapman + Bloom  
 Can. J. Phys. 54 861 (1976)  
 for  $\tau$  and  $E_B$  dep. of  $T$  on  $\text{Ne}_3$   
 wand w/0 strong other  $\tau$  vs  $1/T$

Relaxation of  $^3\text{He}$  on  $\text{H}_2$ -coated substrates covered with a superfluid helium film

sealed 2cm  $\phi$  pyrex sphere

2.4KG JLTP 72, 71 (1988)  
(Sussex group)

14G JLTP 76, 435 (1989)  
(ENS)



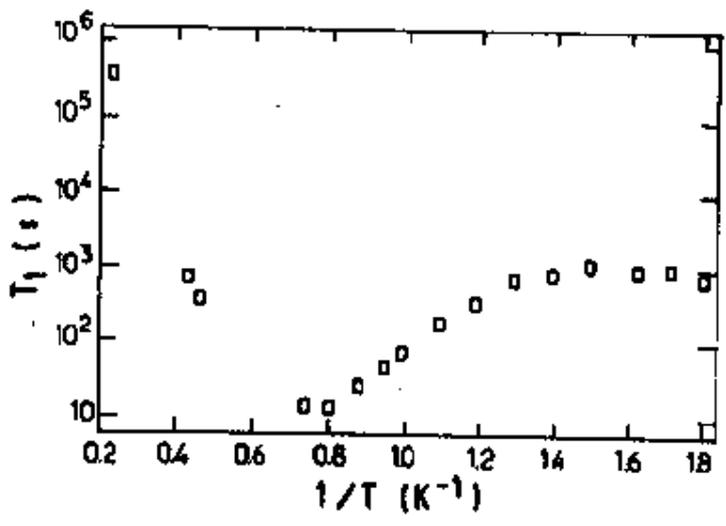
unsaturated superfluid  $^4\text{He}$  film  
( $x \sim 0.5\%$  at 0.5K)

$\text{H}_2$  substrate

Observe  $T_1 \sim 10^4\text{s}$  at 2.4KG and 0.5K  
 $T_1 \sim 10^3\text{s}$  at 14G and 0.5K

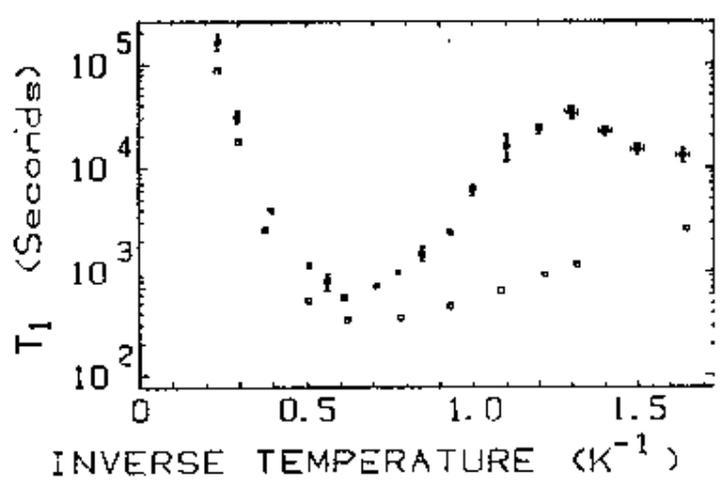
Temp. dep. of relax. rate shows evidence of multiple effects.

!



14G  
ENS data

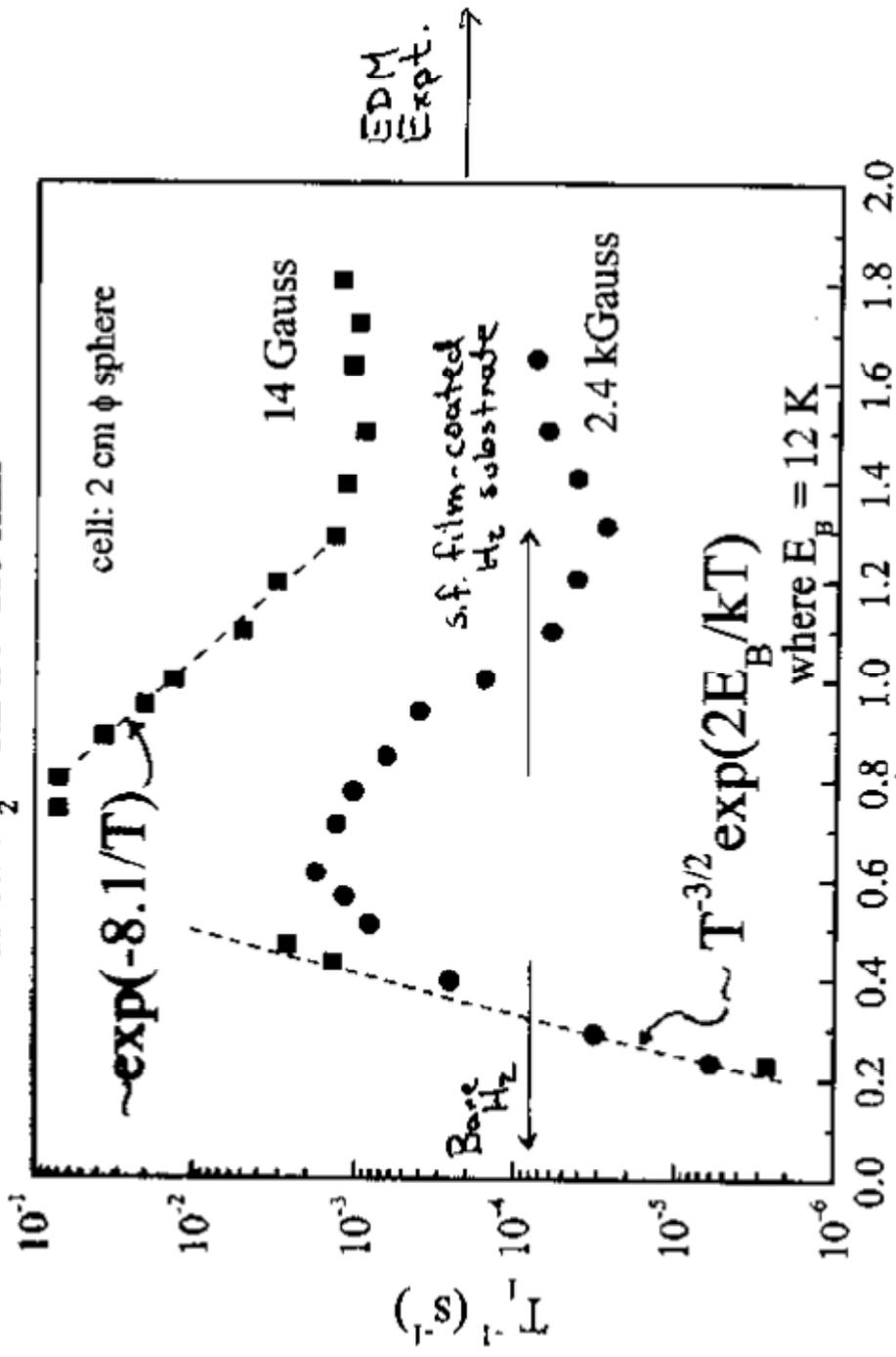
Fig. 2. Longitudinal relaxation time  $T_1$  (logarithmic scale) versus the inverse temperature between 0.2 K and 0.5 K for a particular cell. Lower temperatures are on the right part of the figure.



2.4 KG  
Sussex data

Fig. 4. Values of  $T_1$  measured at 7.7 MHz in sealed Pyrex cells containing <sup>3</sup>He-<sup>4</sup>He-H<sub>2</sub> mixtures. (■)  $n_3 = 3.3 \times 10^{23} \text{ m}^{-3}$ , <sup>3</sup>He:<sup>4</sup>He = 5:1; (□)  $n_3 = 9.8 \times 10^{23} \text{ m}^{-3}$ , <sup>3</sup>He:<sup>4</sup>He = 100:1.

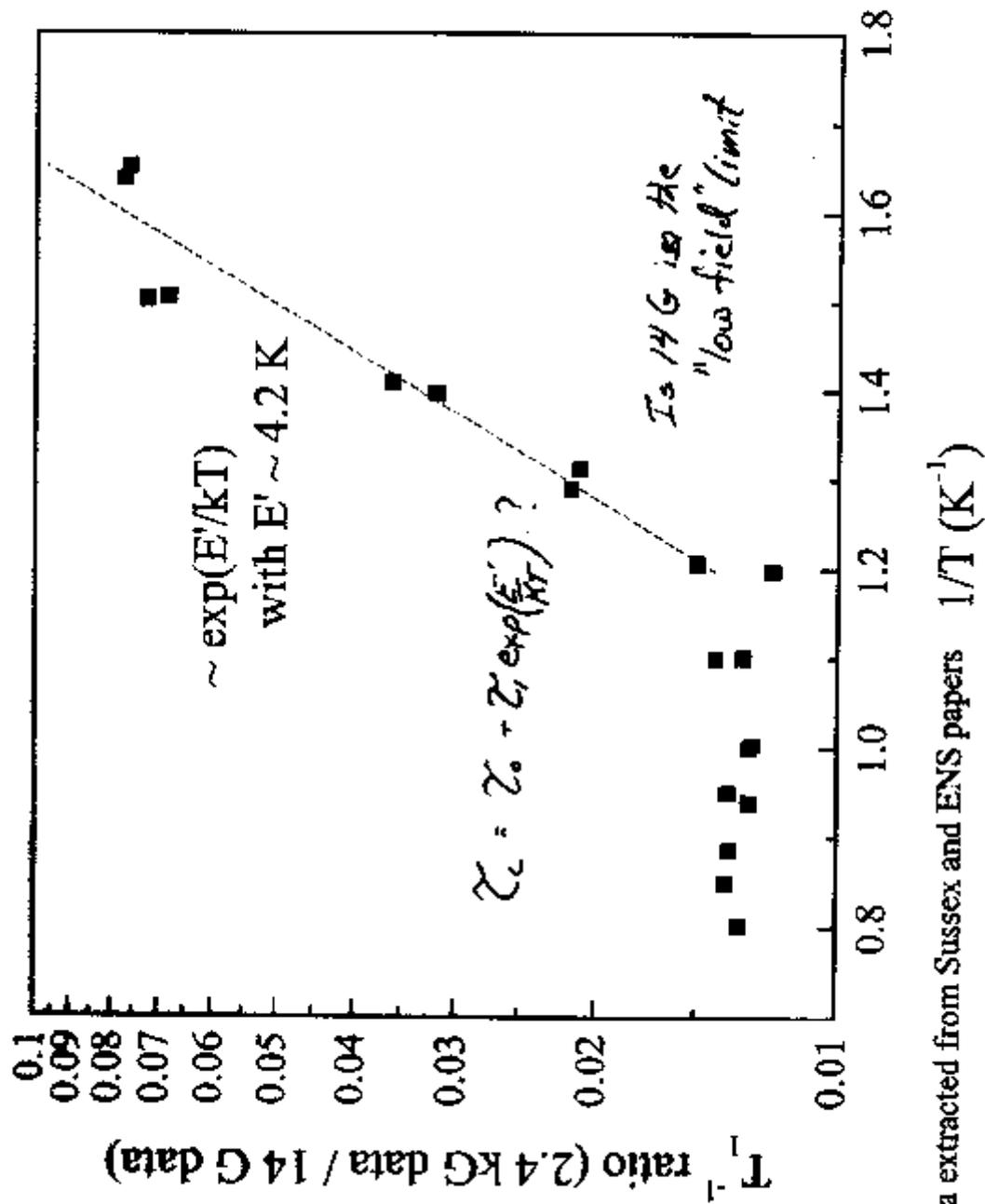
<sup>3</sup>He on H<sub>2</sub> with a l<sup>4</sup>-He film



data extracted from:

2.4 kG - Lusher et al. JLTP 72 71 (1988).  $1/T$  (K<sup>-1</sup>)

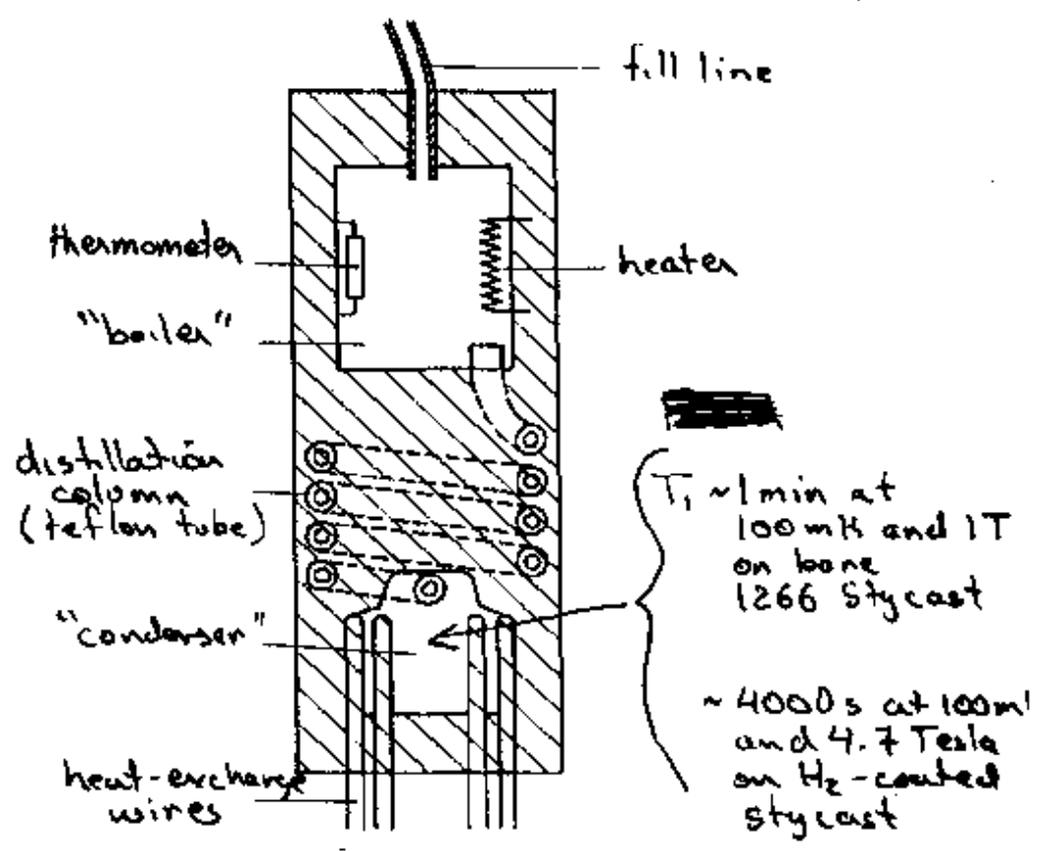
14 G - Himbert & Dupont-Roc JLTP 76 435 (1989).



data extracted from Sussex and ENS papers  $1/T$  ( $K^{-1}$ )

$^3\text{He}$ - $^4\text{He}$  distillation column for producing polarized  $^3\text{He}$

UIC FRL 67 839 (1991)



- $T_1$ 's in teflon tube longer by factor 20
- Stycast sold in metal cans in North America, and glass bottles in Europe!
- $T_1$  roughly prop. to  $T, B$

## Requirements for a "quick + dirty" experiment

### Field

- must be homogeneous
- must explore low field limit to be relevant

### Cell Geometry

- preferably sealed to avoid contamination
- well defined geometric S/V ratio
- \* • crucial to eliminate film from experimental volume

### 3He concentration

- no obvious reason to work in the extremely dilute region (yet!)

Bulk relaxation is not an issue in the relevant temp range PRL 73 2589 (1994)

Conc. dep. of wall term observed by Regay + Tostevin JLTP 126 157 (2006) seems to be a film effect.

### Wall coatings

?

Things to look for

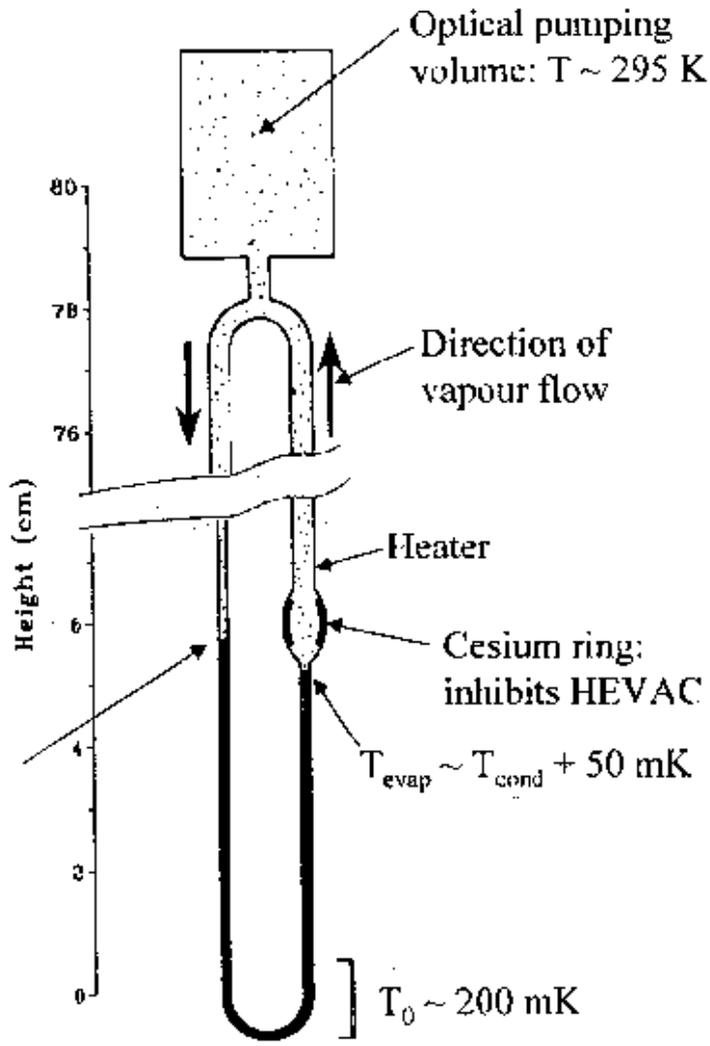
- Frequency dependence of  $T_1^{-1}$  & correlation times
- Temperature dependence of  $T_1^{-1}$ 's binding energies
- ⋮
- Concentration dependence of  $T_1^{-1}$

Some options

- SQUID-detected NMR of (transiently) thermally polarized  $^3\text{He}$
- optically-pumped  $^3\text{He}$  combined with a HEVAR driven circulation loop  
c.f. PRL 73 2587 (1994).  
(compatible with ~~some~~ conventional or SQUID-detected NMR)

# Apparatus for Production of High Nuclear Polarization in Liquid $^3\text{He}$ - $^4\text{He}$ Mixtures

*Phys. Rev. Lett.* **73**, 2587 (1994)



Evolution of the <sup>3</sup>He Magnetization

peak splitting:  $\nu - \nu_0 = A(3\cos^2\theta - 1)\gamma\mu_n M / 2\pi$

↑  
measures *M*

